

# Evidence of multiple scattering in DPR observations and way forward for retrievals

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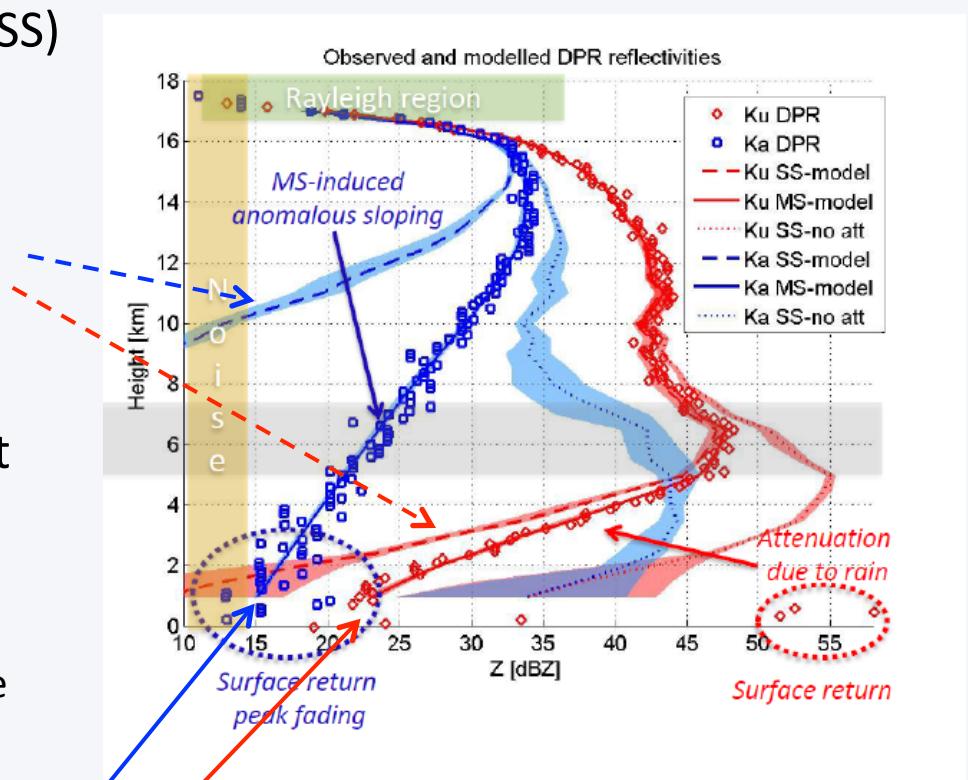
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# Multiple scattering (MS) with radar observations

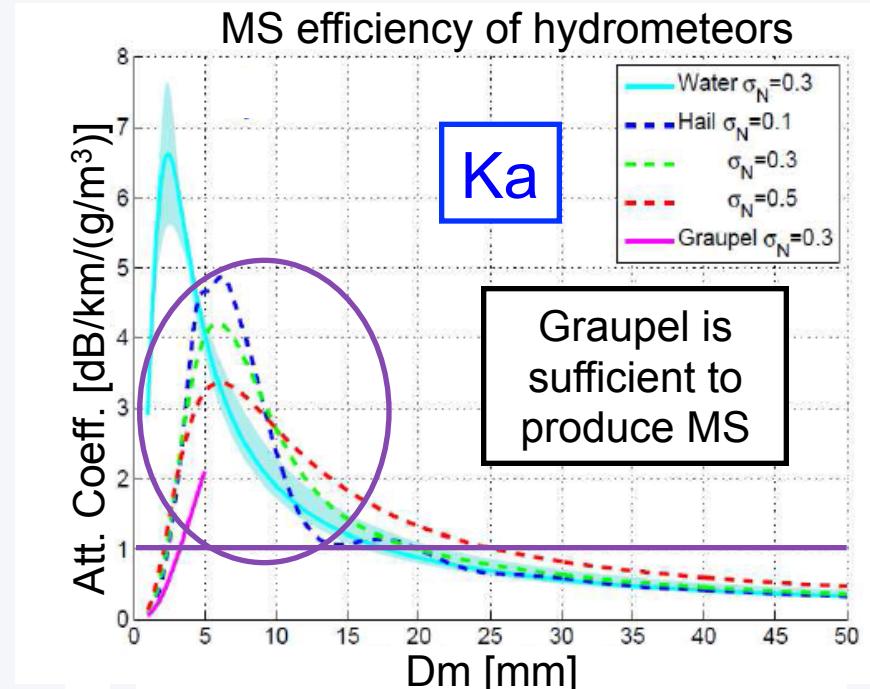
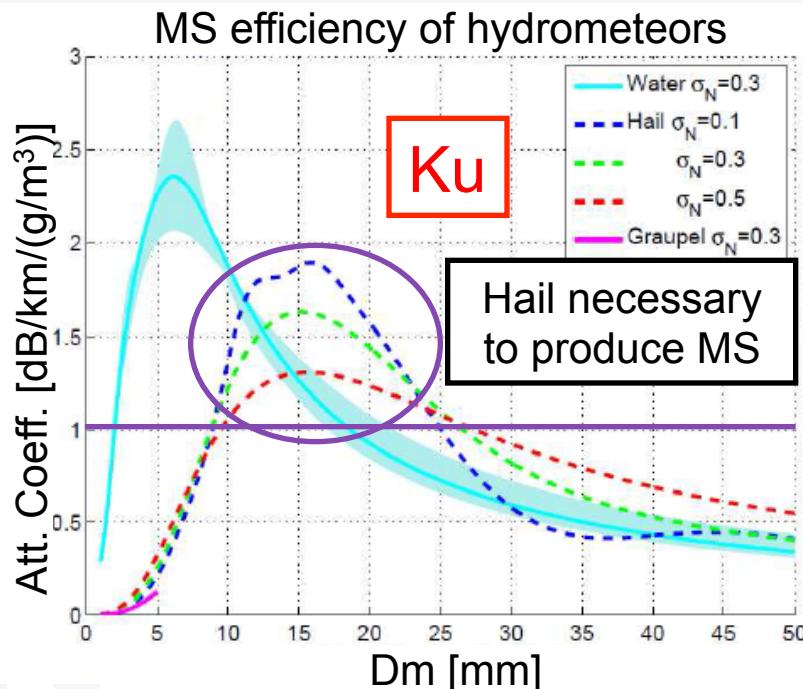
- Key assumption in single scattering (SS) theory: any scattered wave is not detected except those in the exact backscatter direction  
→ scattering = absorption
- Conditions typically experienced by ground-based radar systems, but not by satellite-borne radars
- Key ingredients for MS:
  - High extinction (attenuation)  $k_{\text{att}}$  → more MS at high frequencies
  - High scattering ( $\omega$  close to 1) → more MS for highly scattering particles (snow, graupel, hail)
  - Mean free path ( $1/k_{\text{att}}$ ) smaller than FOV → satellite-borne radars more prone to MS



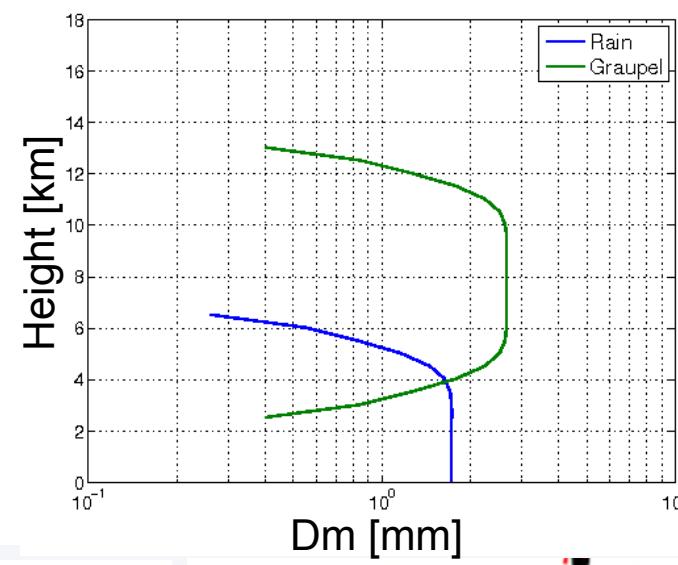
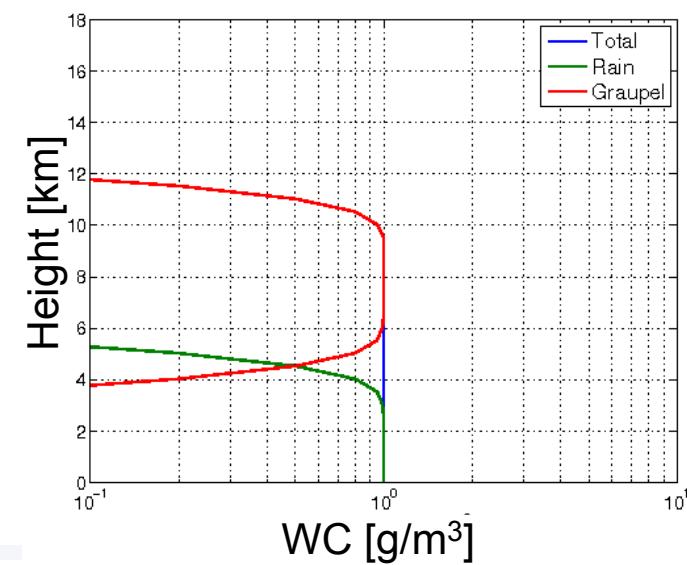
Battaglia, Tanelli, Mroz, and Tridon, 2015,  
Multiple scattering in observations of the GPM  
dual-frequency precipitation radar: Evidence  
and impact on retrievals. *J. Geophys. Res.  
Atmos.*

# Ingredients of multiple scattering (MS)

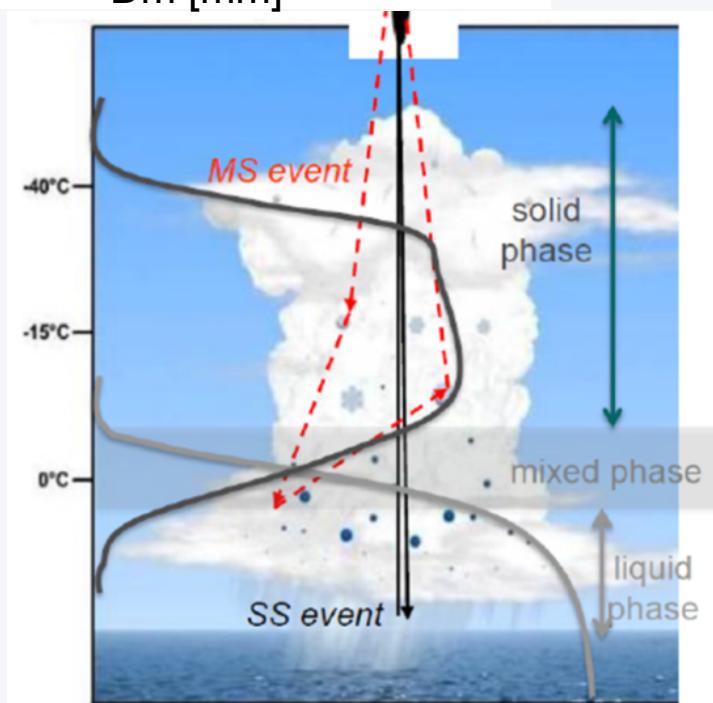
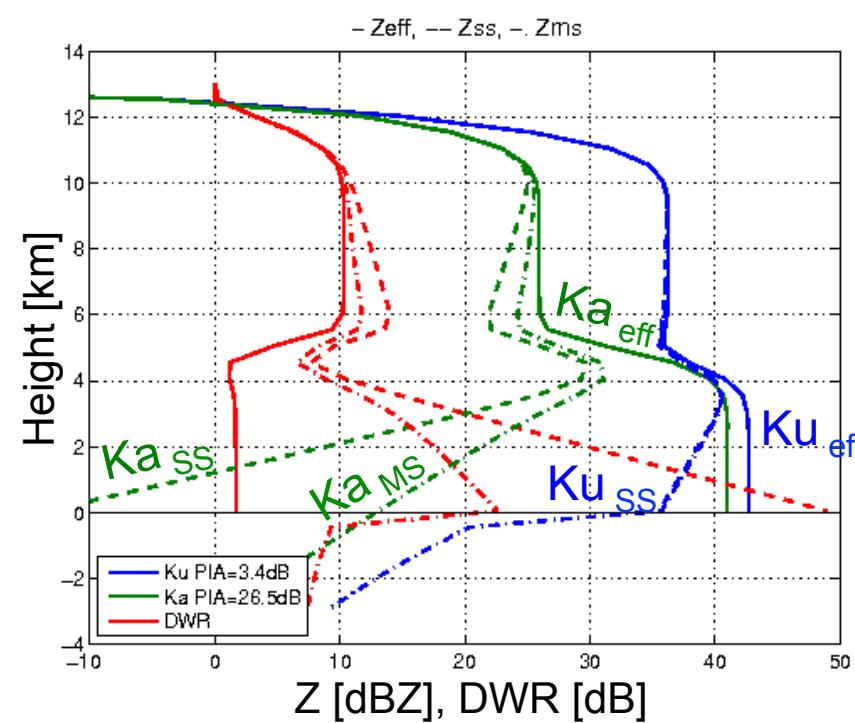
- Tables of  $k_{att}$  for various hydrometeor types (water, hail, graupel) at Ku and Ka bands
- DPR beam width  $\approx 4\text{-}5 \text{ km} \rightarrow \text{MS if } k_{att} > 1 \text{ dB/km}$  (roughly speaking)
- For a reasonable WC of  $1 \text{ g/m}^3$ , classes producing attenuation higher than  $1 \text{ dB/km}/(\text{g/m}^3)$  are prone to MS
- Water produces less MS because of its low  $\omega$ ,  $k_{att,Ka} \approx 6 * k_{att,Ku}$



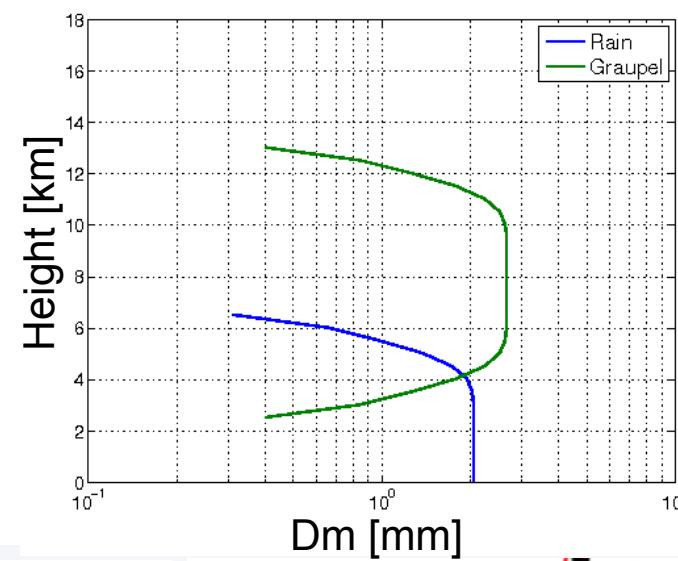
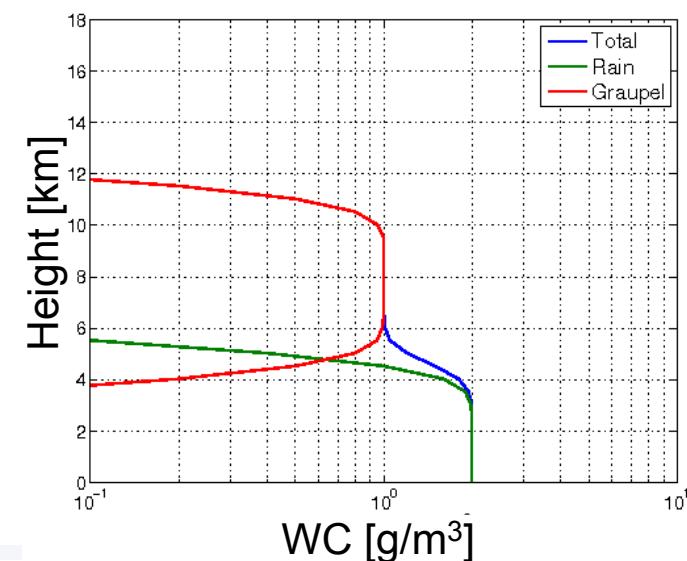
# Synthetic Ku-Ka observations



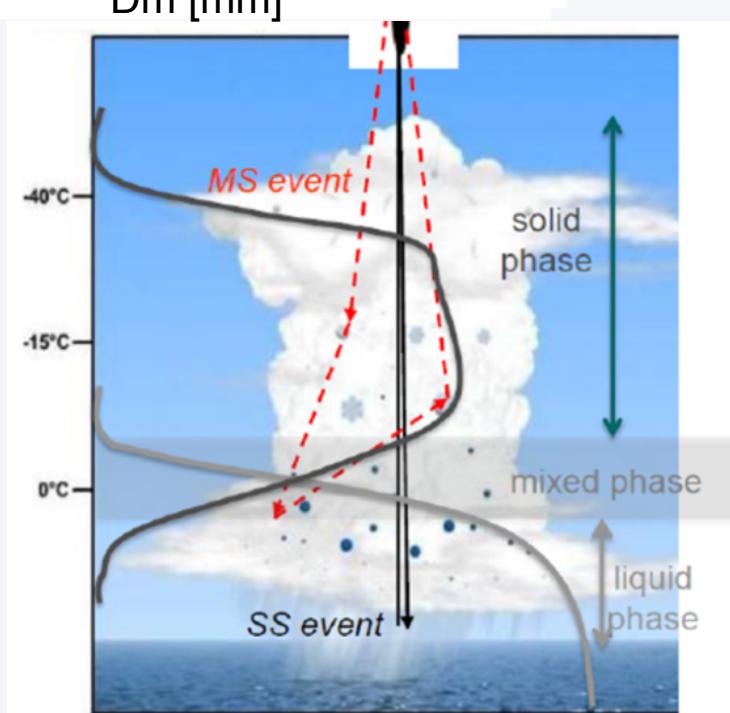
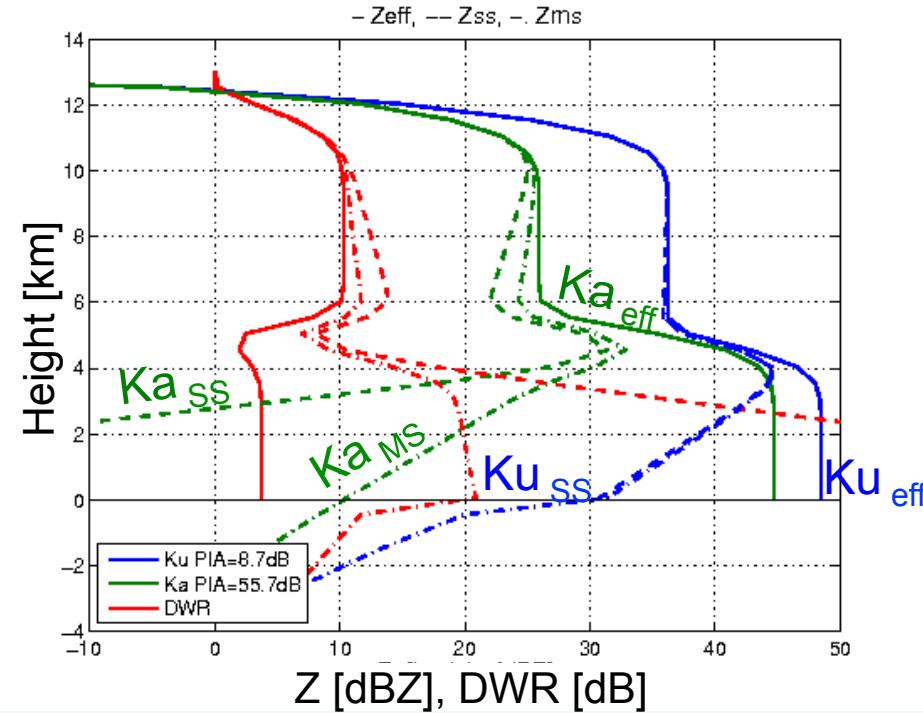
$R = 20$   
mm/h



# Synthetic Ku-Ka observations



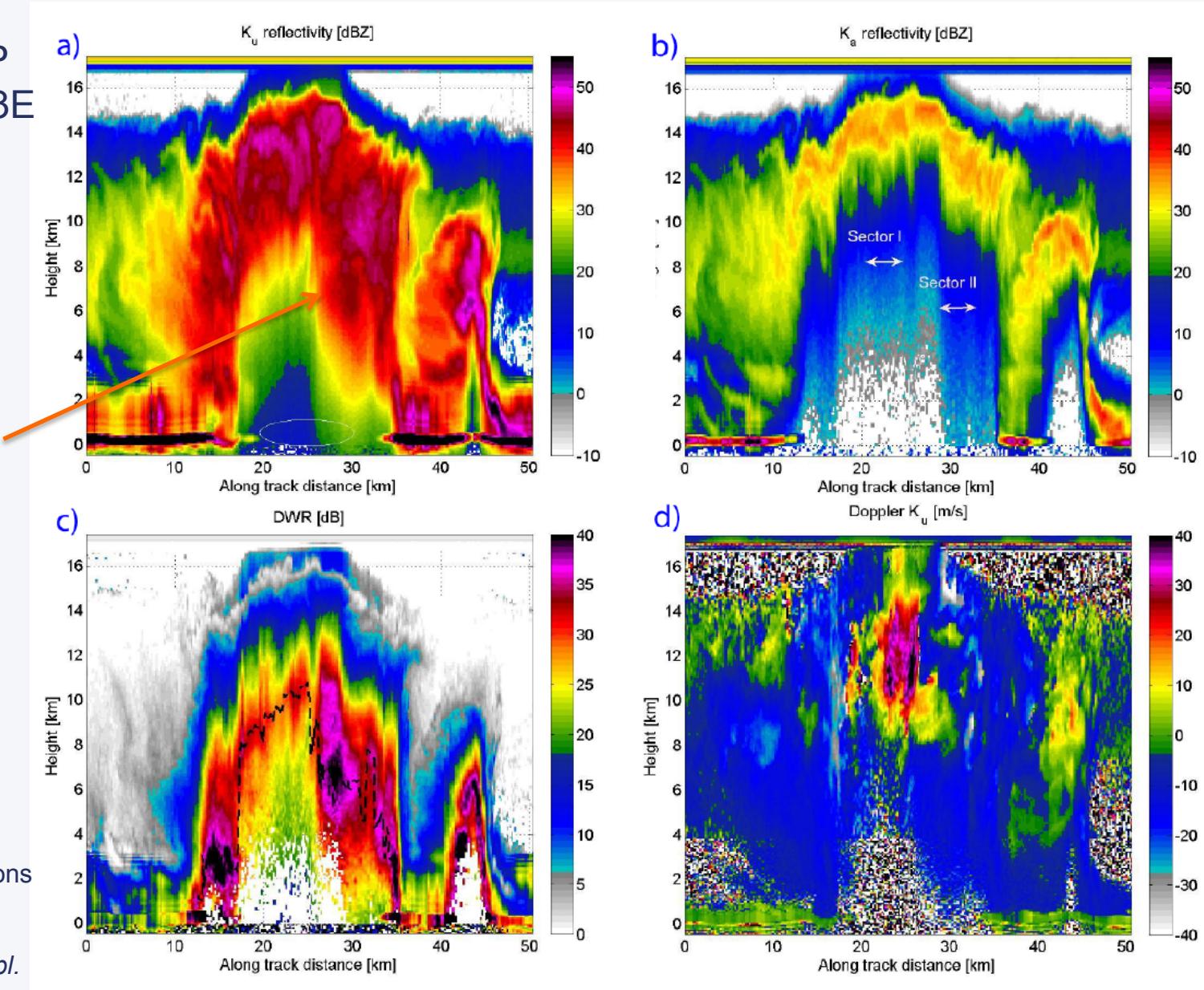
$R = 44$   
mm/h



# Before GPM launch: MS in airborne Ku-Ka

NASA-HIWRAP  
radar during MC3E

Region of  
strong  
attenuation  
Very likely  
presence of  
hail (ground  
reports+  
Ground-based  
S-pol radars)

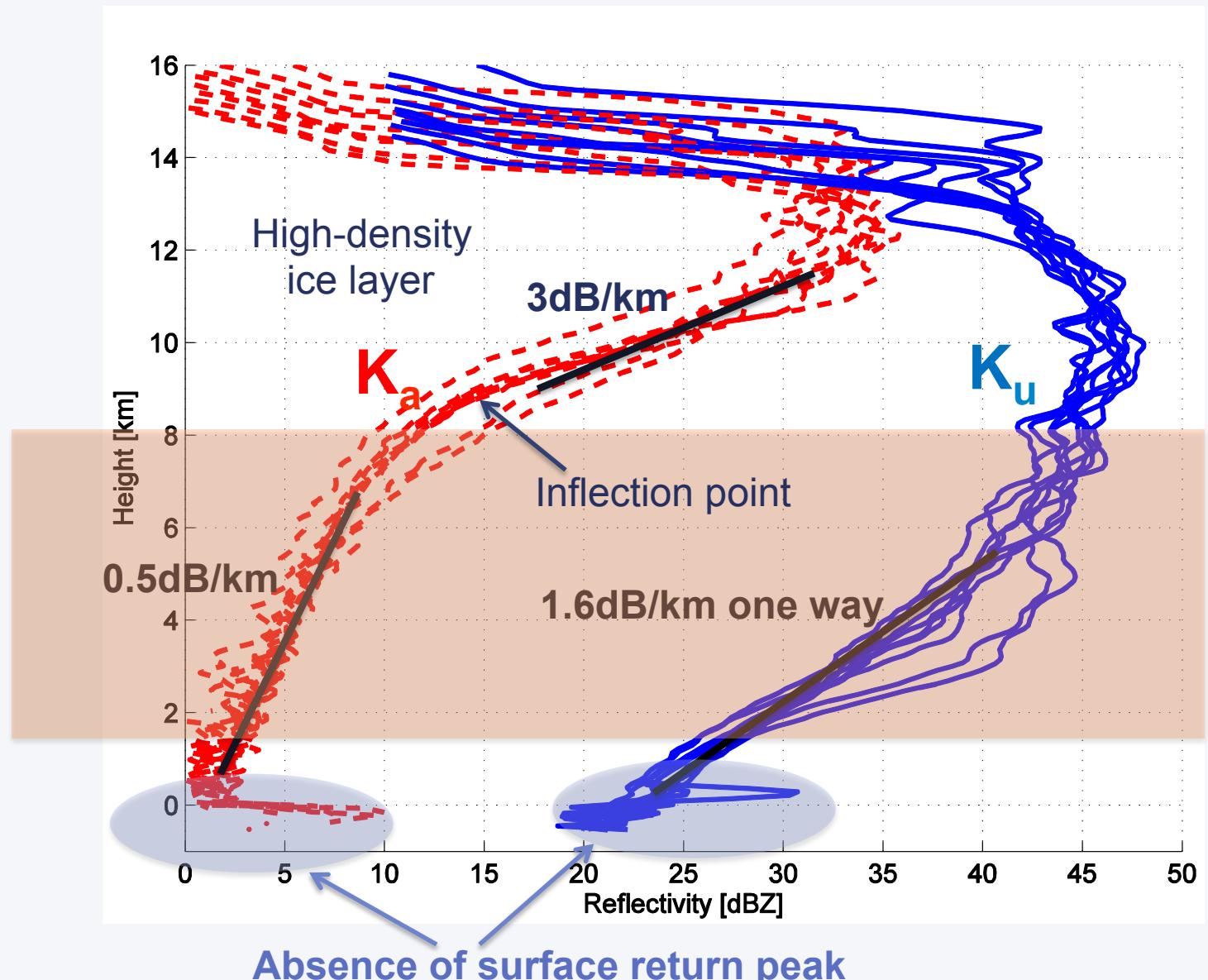


Heymsfield et al., 2013:  
Airborne Radar Observations  
of Severe Hail Storms:  
Implications for Future  
Spaceborne Radar, *J. Appl.  
Meteorol. Climatol.*

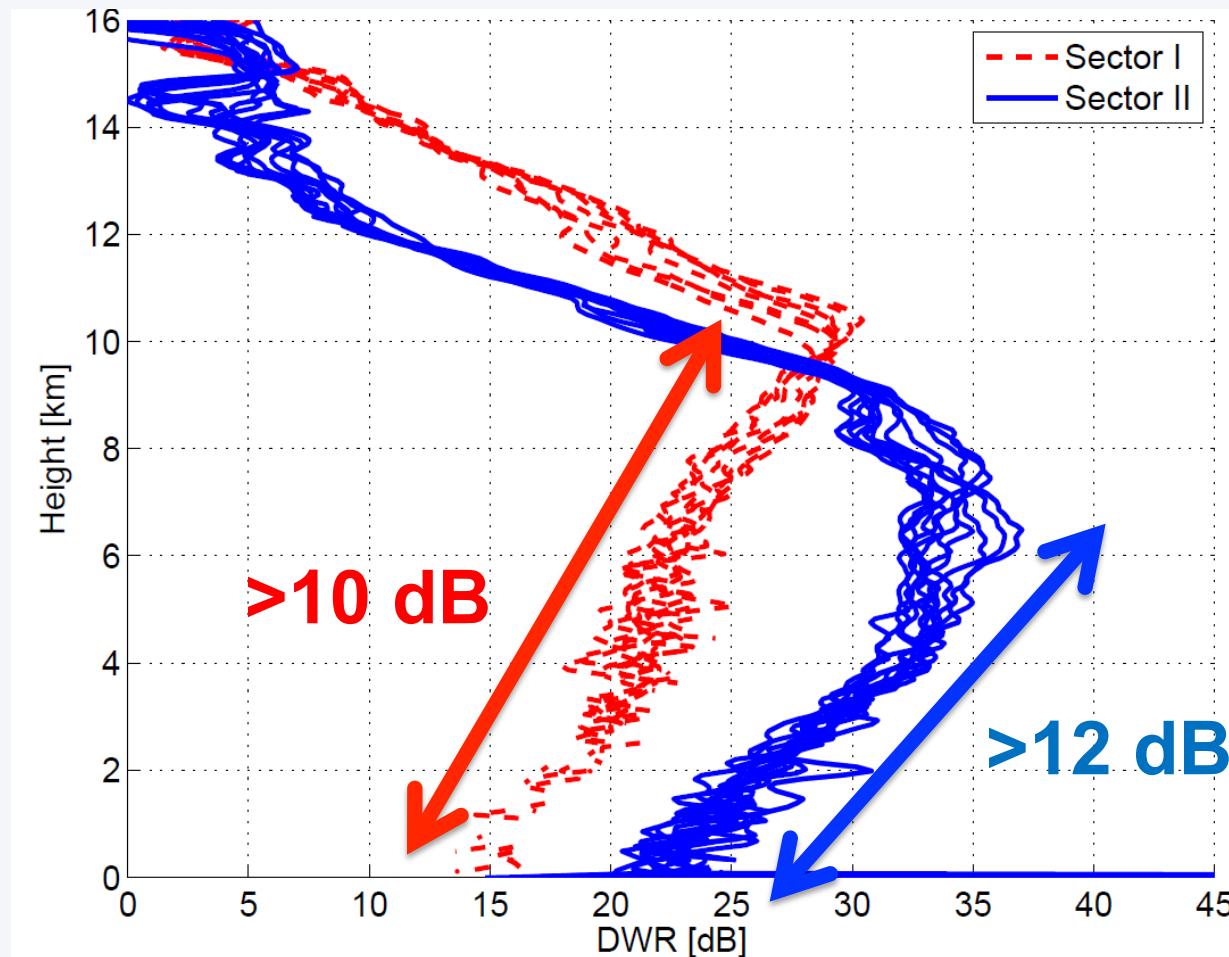
# Vertical reflectivity profiles in sector II

S-band Z  
above 60  
dBZ only in  
the last 4 km

Anomalous sloping  
→ DWR knee



# The Dual Wavelength Ratio knee

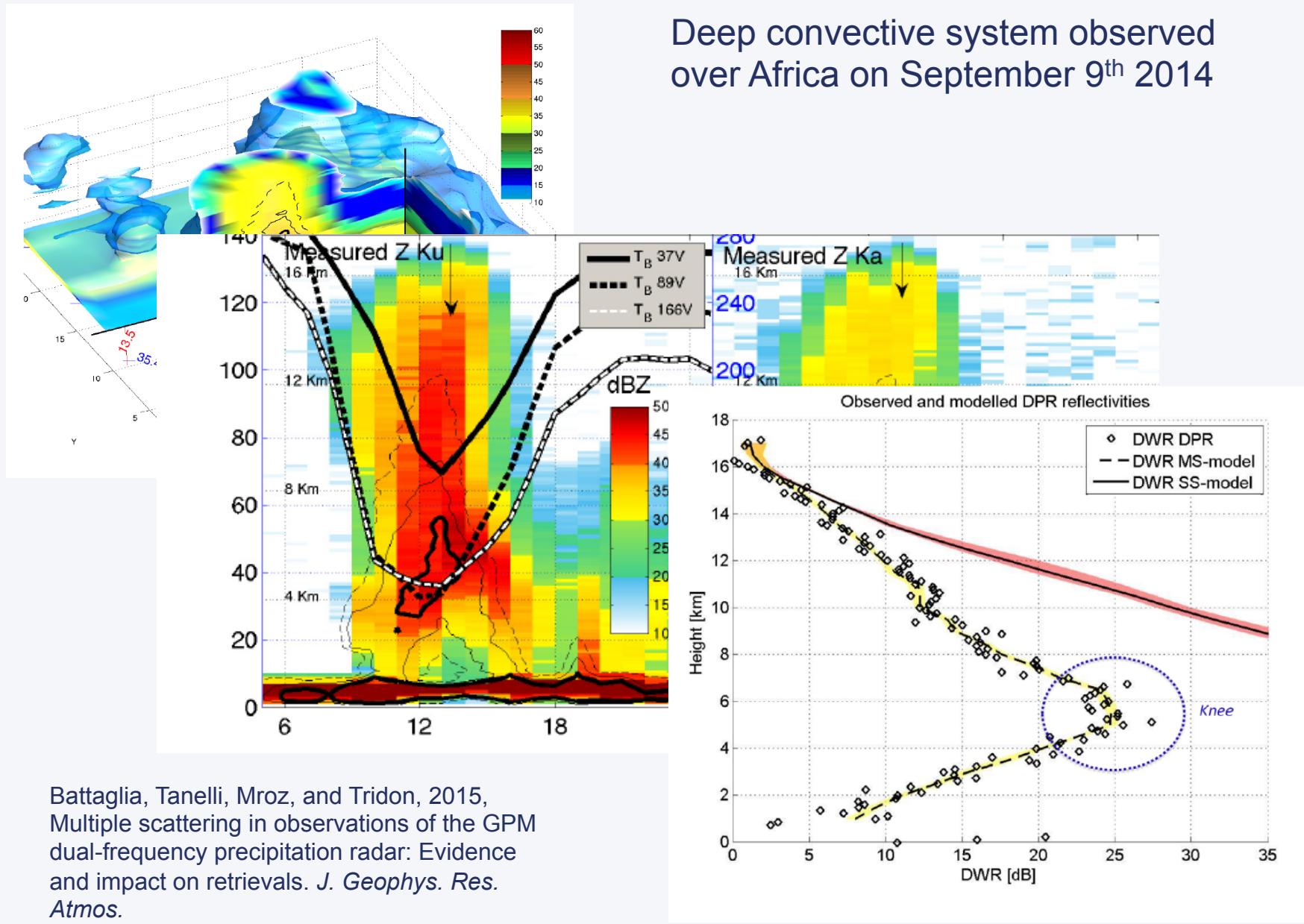


This feature was observed during MC3E in several convective cells before GPM launch

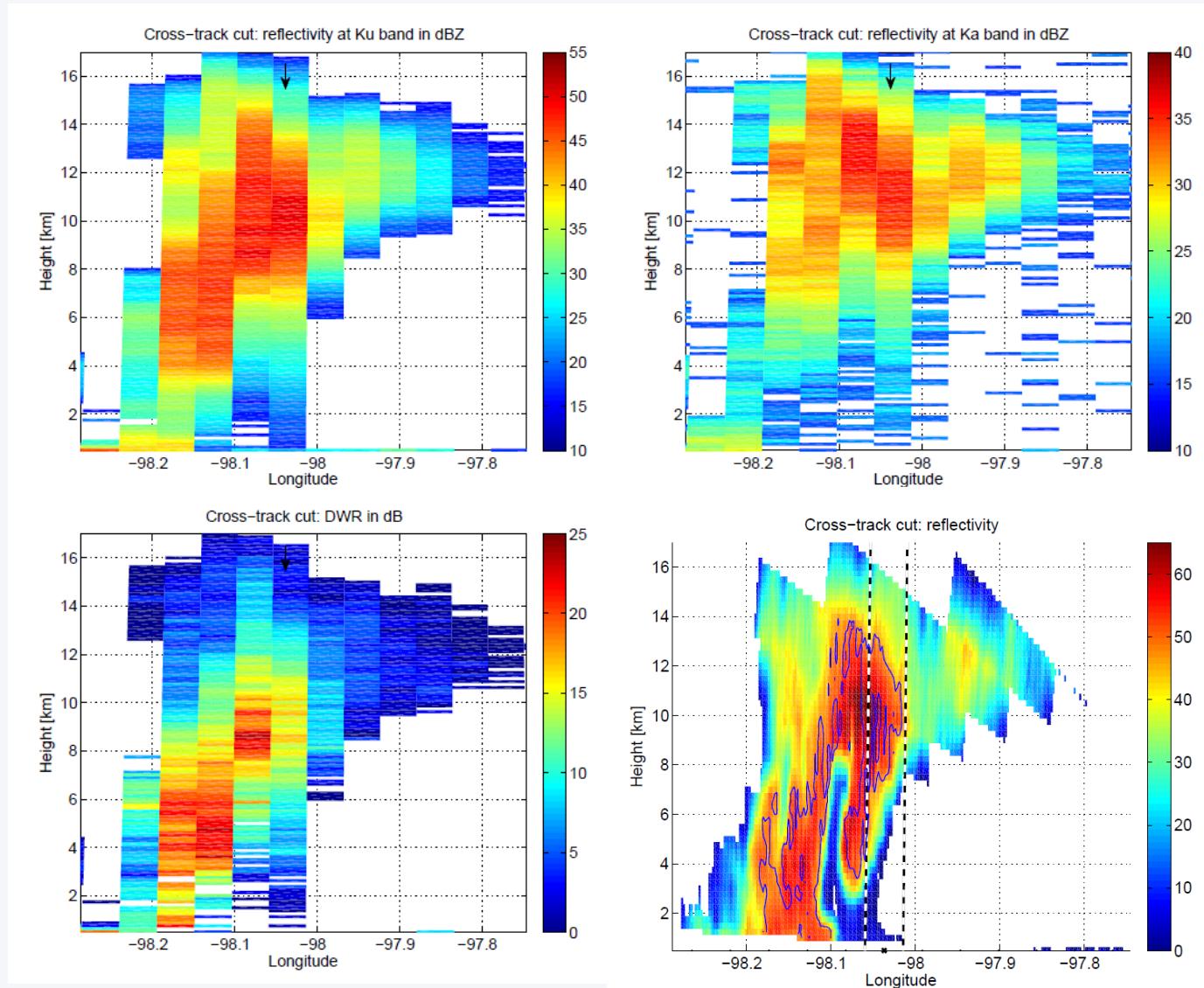
Battaglia et al., 2014: The DWR Knee: A Signature of MS in Airborne Ku-Ka Observations, *J. Appl. Meteorol. Climatol.*

- Distinct characteristic regimes → retrieval of the ice properties which can produce these features (premises of a variational algorithm)
- Quite astonishing to see these features in Ku-Ka airborne observations → predicted to be more pronounced in GPM observations

# The DWR knee observed in DPR observations



# MS with DPR: supercell over Texas

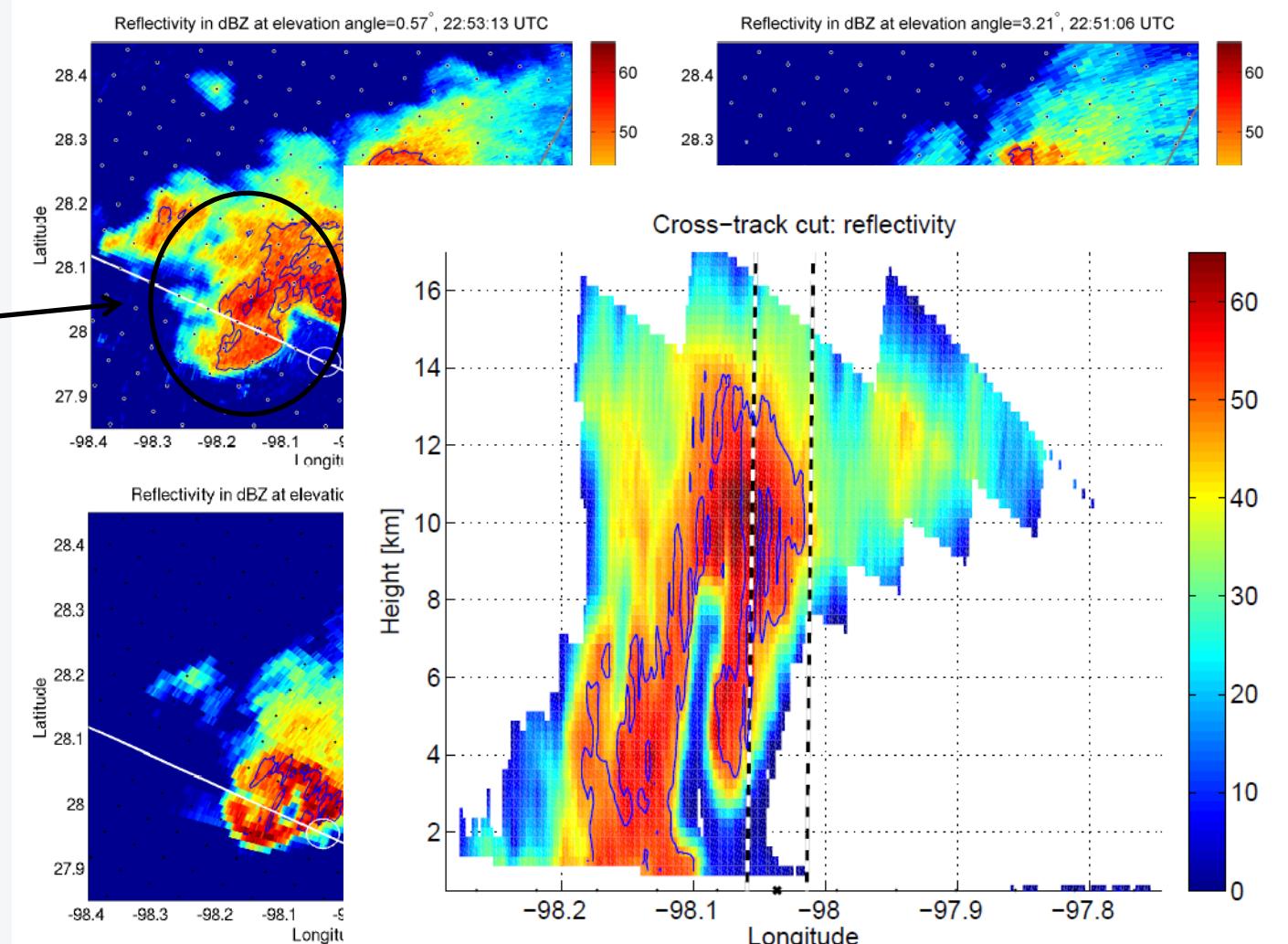


NEXRAD  
S-band Z

# MS with DPR: ground-based observations

NEXRAD  
S-band Z

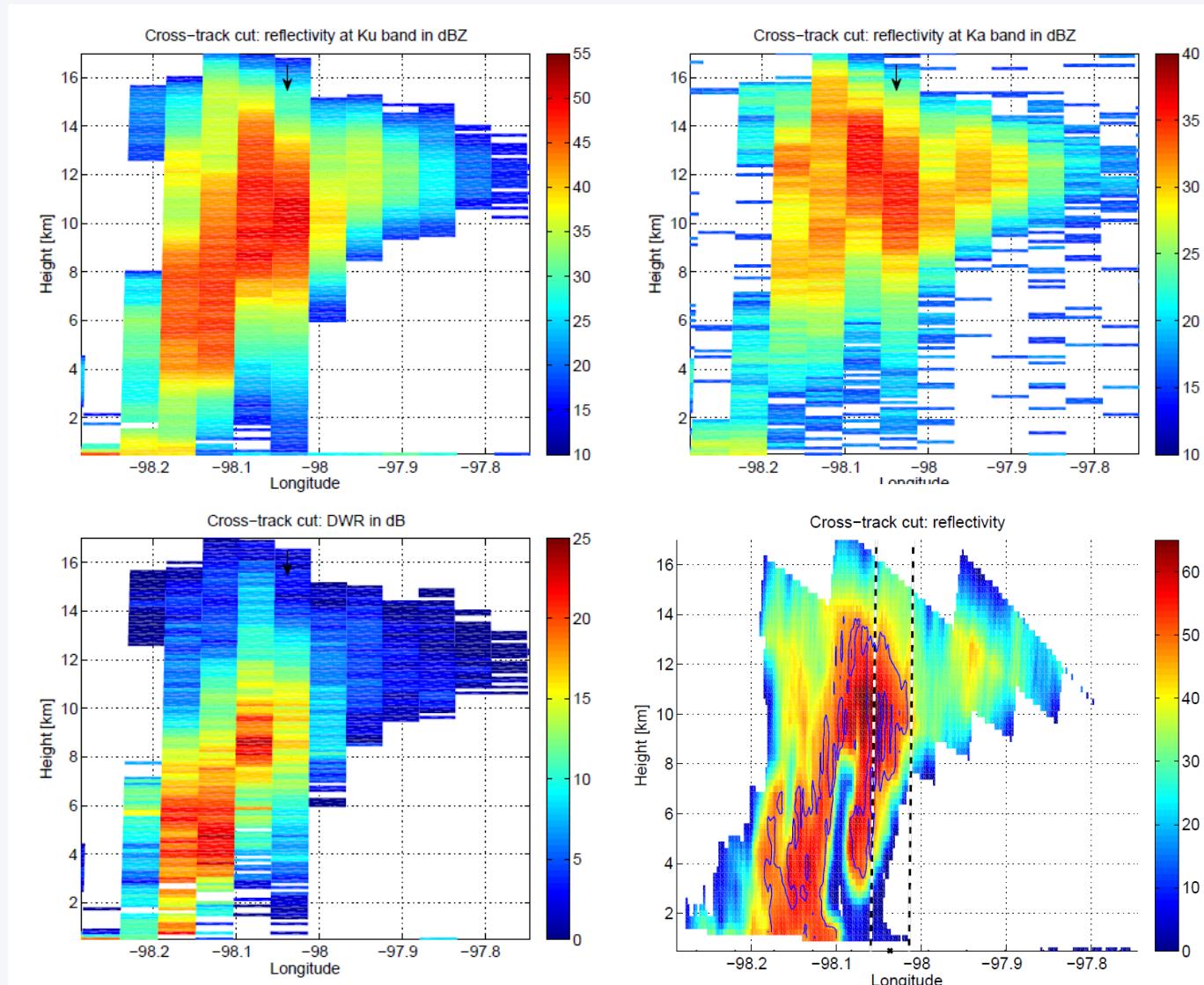
Hook echo:  
Characteristic  
of mesocyclone  
circulation



- Tilted rotating updraft (white circle)
- Presence of hail (75% probability contour)

Heinselman and Ryzhkov, 2006:  
Validation of polarimetric hail  
detection. *Wea. Forecasting*,

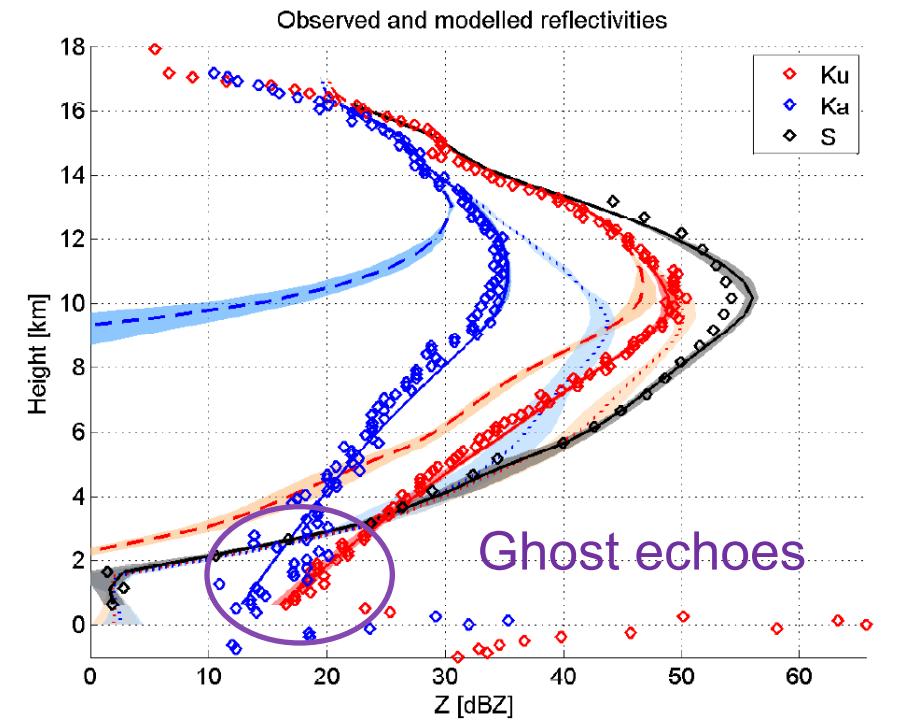
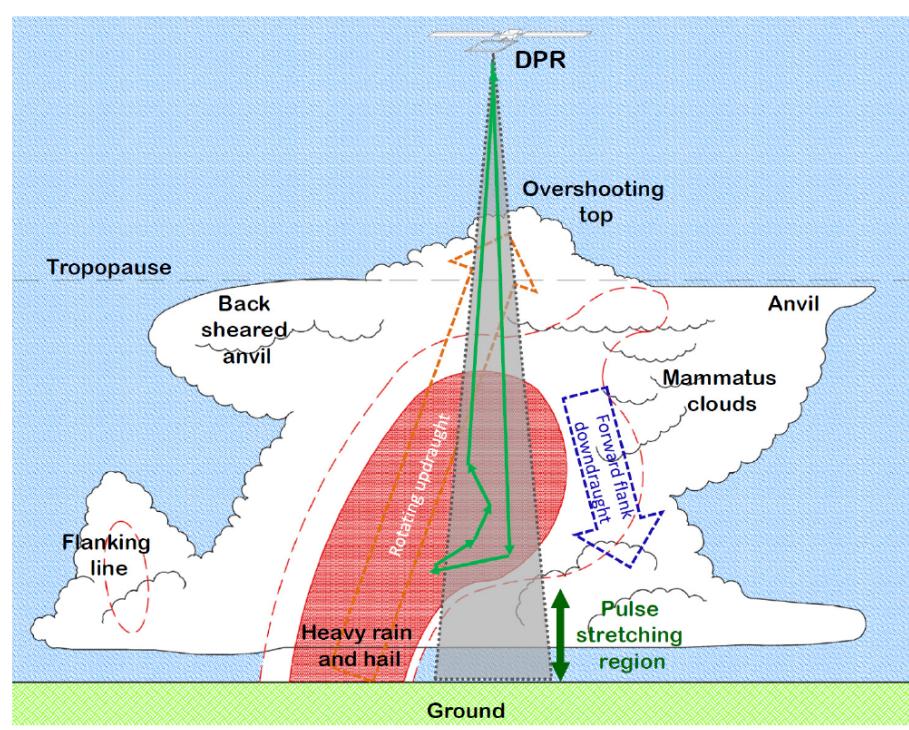
# MS with DPR: supercell over Texas



- Reconstruction of S-band “GPM-like” profiles (MRMS product, P. Kirstetter)

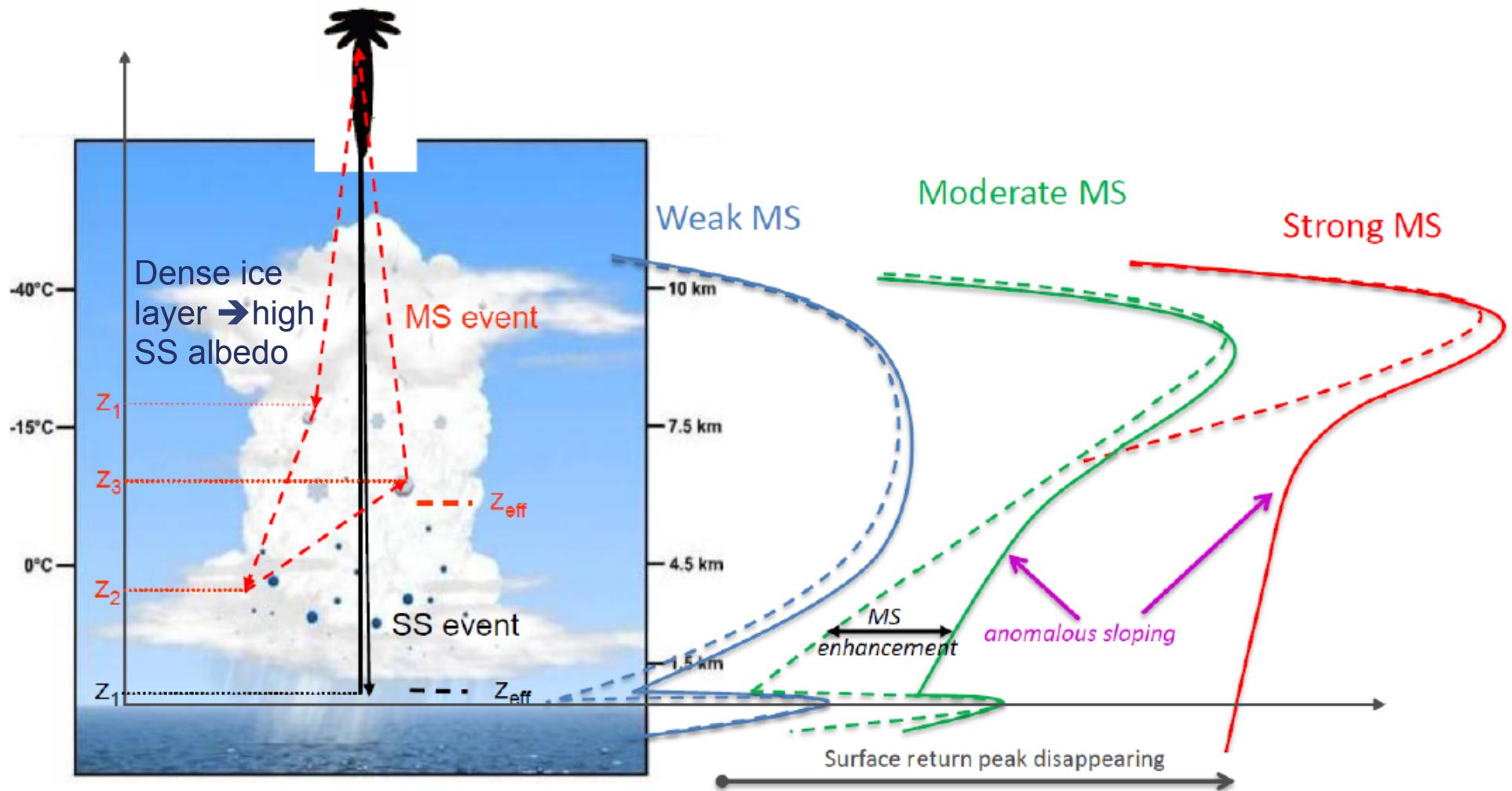
# MS with DPR: Ghost echoes

- Triple frequency profiles
  - Validation of Ka-Ku retrieval by comparing forward modelled S-band reflectivity
  - Triple wavelength retrieval (support the presence of hail)
- Tilted convective core: no rain at the ground (S-band) → MS at Ka and Ku



Battaglia et al., submitted: Multiple-scattering-induced “ghost echoes” in GPM-DPR observations of a tornadic supercell, *J. Appl. Meteorol. Climatol.*

# Challenge: intermediate regimes, weak to moderate MS



- The DWR knee is a signature of strong MS enhancement
- Weaker MS more difficult to assess but still affects reflectivity profiles

# Summary

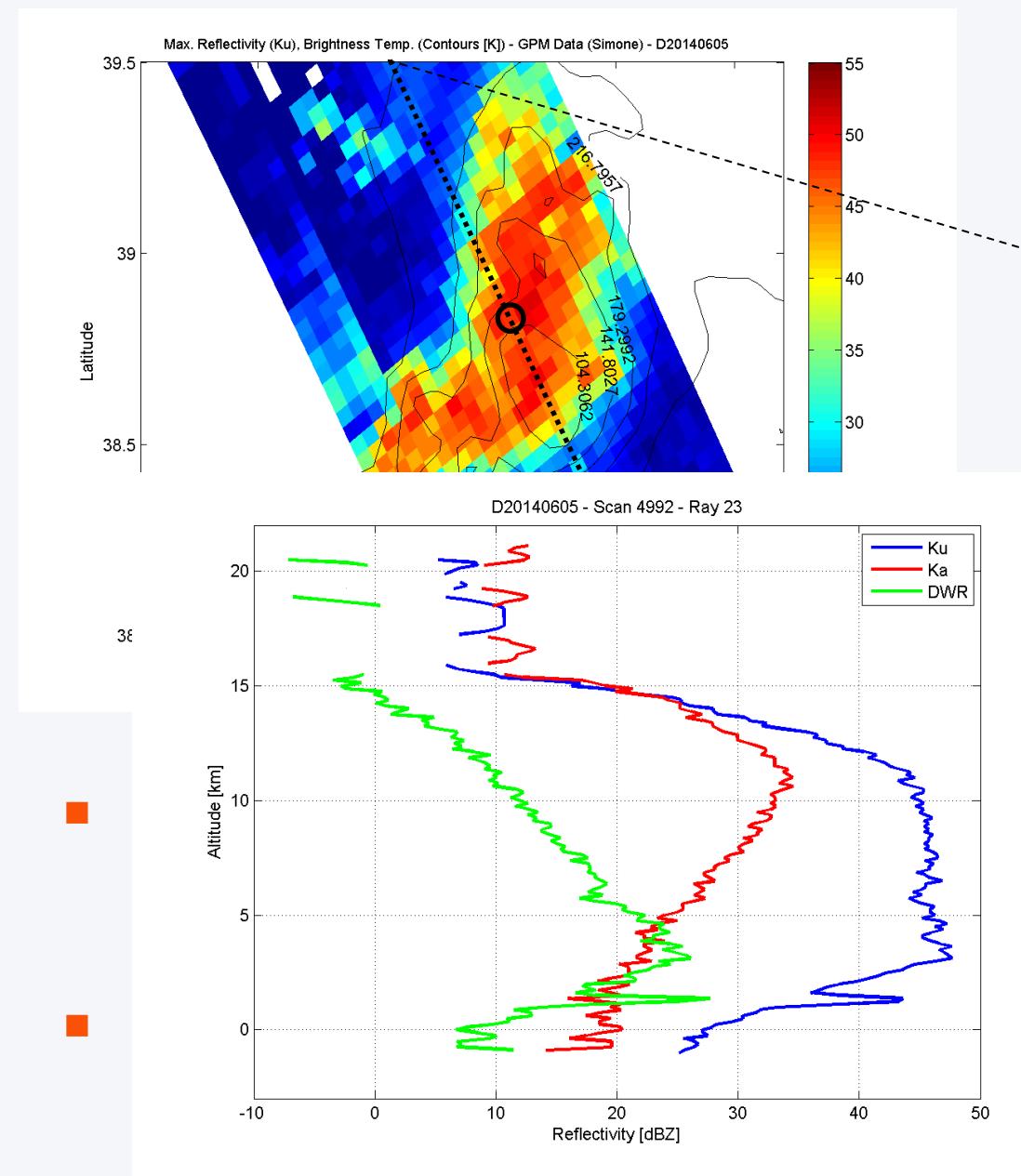
- Signature of strong MS
  - Absence of surface reflectivity peak
  - Anomalous small reflectivity slope in the bottom part of profiles → DWR knee
  - Signal extending below surface
- MS identified in GPM observations
  - High-density ice shafts embedded in large convective systems produce a lot of MS at Ka band
  - MS in Ku band has also been identified in a particular case
- Generalise the detection of MS
  - Flag contaminated profiles using MS signatures
  - Profiles usually contaminated by NUBF as well
- Use MS signal to refine the inversion problem
  - Retrieval including a forward simulator accounting for MS
  - Use the MS signal to further constrain the retrieval of the scattering layer (ice aloft)
  - Infer the rain rate in a statistical way?

Presentation by  
Simone Tanelli  
(Thursday 1:20 pm)

**Thanks for your attention**

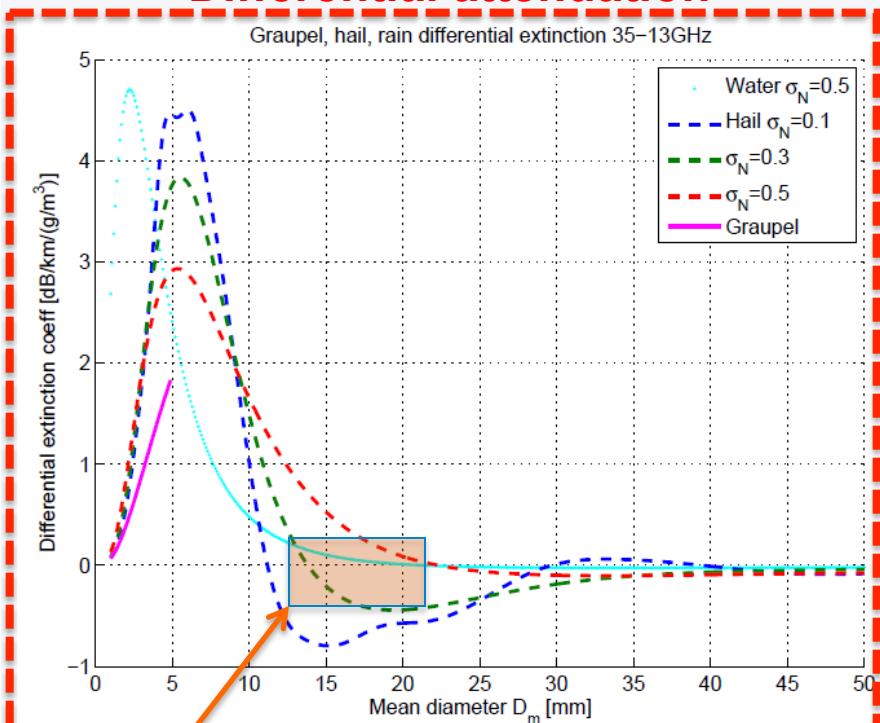
Questions?

# Second marker of MS

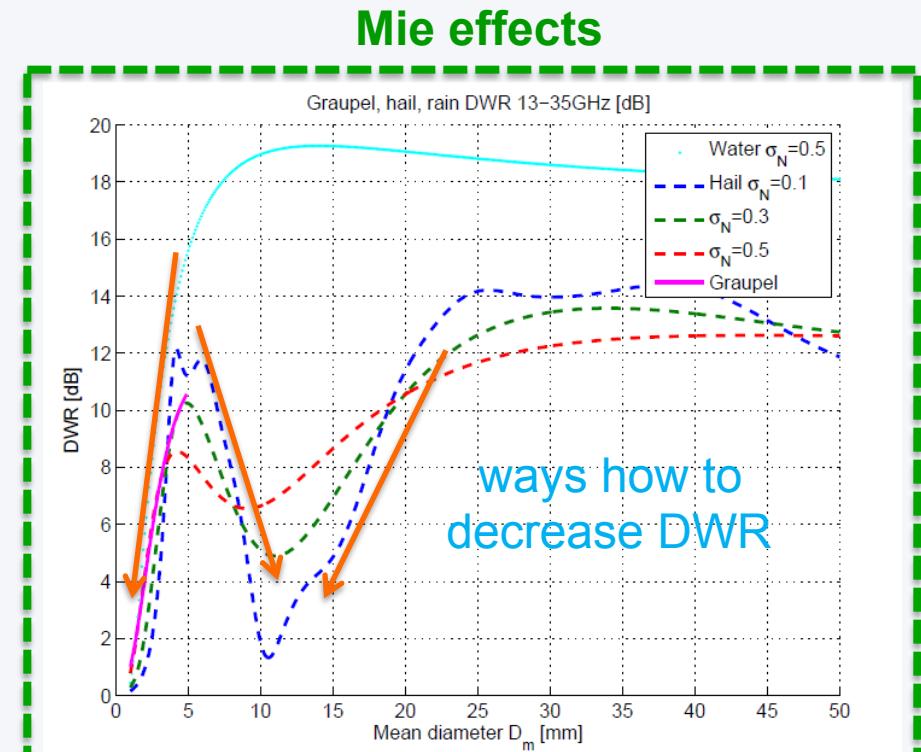


# Single scattering explanation? DWR sources from hail/graupel/rain

## Differential attenuation



Only hail particles in this range of size  
But almost monodisperse can  
produce a  
decrease in DWR. Rain and wet hail  
cannot!!



However quite hard to produce a 12 dB effect! Vertical microphysical processes not supported by S-band observations.

Even if DWR can be explained there is no explanation of the disappearance of the surface with realistic  $\sigma_0$  values